Deep Learning Models for Retinal Disease Diagnosis and Classification

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

by

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It is the work that is expected to be carried out under the supervision of Prof. Parneeta Dhaliwal and co-supervision of Dr. Deepak Gupta.

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ABSTRACT

One of the most active areas of study in medical image categorization is computer-aided diagnosis of ocular diseases. Several eye conditions, including diabetic retinopathy, age-related macular degeneration (AMD), retinal vein occlusion (RVO), Glaucoma may result in partial or total blindness. When it comes to diagnosing eye problems, fundus imaging and optical coherence tomography (OCT) imaging are often used. By assisting physicians with diagnosis and treatment, automated ocular disease diagnosis can save medical resources, lower treatment costs, and improve patients' chances of early detection and treatment. Since Deep Learning can learn complicated patterns in retinal images and accurately predict a wide range of eye ailments, it is a crucial tool for the automated diagnosis and categorization of numerous retinal diseases. Using publicly available retinal image datasets, this research aims to construct a new deep learning model that effectively classifies numerous retinal illnesses.

Key words: Retinal Disease, OCT, Fundus, Multiclass Classification, Deep Learning

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1. Introduction

1.1 **Background**

The retina is a complex and sensitive organ that significantly influences daily life. Eye disorders including glaucoma, diabetic retinopathy, age-related macular degeneration, choroidal neovascularization, retinal detachment, retinal vein occlusion, and retinoblastoma can have serious repercussions. These include blurred vision and the risk of blindness if not identified promptly Fatima et al. (2024).

It is clear that there is a significant impact on the general population; impaired vision might result in a diminished quality of life, reduced autonomy, and an increased risk of accidents. Moreover, there are socio-economic consequences such as heightened healthcare expenses, diminished productivity, and the individual and community obligations of supporting persons who experience visual impairment Bali and Mansotra (2024).

Timely recognition and accurate identification of eye disorders are essential for successful treatment and avoiding or postponing vision impairment. Consequently, improvements in identification and categorization methodologies, such as computer-aided system for detection of disease using deep learning, are crucial for addressing such issues. Muchuchuti and Viriri (2023).

In recent decades, substantial progress has been made in the identification of eye disorders. This advancement has transitioned from conventional manual assessments by eye specialist to the development of computerized assisted methods. The key elements driving this transformation include the increasing prevalence of eye disorders, the need for enhanced and accurate assessment techniques, and the rapid advancements in image processing and deep learning technologies. Eye Specialists have typically depended on manual eye testing as the standard procedure; nevertheless, this method was arduous, unreliable, and prone to observer variability. Fatima et al. (2024)

Fundus and OCT imaging datasets are used for automatic diagnosis of retinal disorders using deep learning. Using OCT dataset presents two challenges. To start, when compared to datasets used in typical image analysis domains, the public retinal OCT

image datasets is far lower in size. Furthermore, the size and quality of retinal OCT images acquired from various tissues can vary greatly; this is in addition to the fact that clinical medicine practitioners often deal with retinal OCT images that exhibit even more pronounced variations.

1.2 **Retinal Disease overview**

ERM: Epiretinal membrane, also referred to as macular pucker, is a disorder where a delicate, transparent layer of scar tissue develops on the surface of the macula, which is the area of the eye that is crucial for central vision. This membrane can constrict and crease the retina, resulting in distorted and blurred vision (Patil et al., 2024).

RVO: Retinal vein occlusion refers to a blockage in the small veins responsible for draining blood from the retina. This obstruction can lead to vision impairment due to retinal ischemia, macular edema, and the development of abnormal blood vessels (You et al., 2007) (Fung et al., 2021).

AMD: Age-related macular degeneration represents a significant contributor to vision impairment among the elderly population. Under this condition, the macula, which is the region of the eye that facilitates central vision, experiences degeneration over time. (You et al., 2007)(Fung et al., 2021)(Keel et al., 2017).

Drusen are yellow deposits of extracellular material that build up beneath the retina. Their presence is a risk factor for the development of age-related macular degeneration (You et al., 2007).

Myopia, or nearsightedness, is a refractive error where the eye is unable to properly focus light, leading to blurred distant vision.

2. Brief Literature Survey

Sengar et al. (2023) designed a system to train and evaluate fundus pictures for the diagnosis of different ocular conditions like AMD, Diabetic Retinopathy, Media Haze, Glaucoma, amblyopia, and cataracts, utilizing a keystone convolutional neural network to extract pertinent characteristics from the input color fundus image collection, which are subsequently employed to generate predictive diagnostics. The efficacy of the "EyeDeep-Net" is assessed through various performance metrics, revealing that the proposed model markedly outperforms several leading baseline models. The proposed model got validation accuracy of 82.13% and testing accuracy 76.04%. They also did a comparison of the suggested methodology with the latest techniques, demonstrating its effectiveness in categorization and disease identification using digital fundus images.

Bali and Mansotra (2024), reviewed the deep learning techniques to analyze and synthesize existing research on deep learning models for ocular disease diagnosis and assess the performance of these models.They also highlight the challenges such as size and diversity of datasets, class imbalance, and data annotation. According to their survey, the LeNet model has an accuracy rate of 99.8%. GoogleNet accuracy rate of 81%. VGG19, ResNet152, and DenseNet201 (AUC) of 90%. Hybrid CNN and Random Forest accuracy of 93.1% U-Net Deep CNN accuracy is 98.82%.

Patil et al. (2024) developed two models: "faster ensembles" and "ensembles of ensembles" using deep learning. Both models are constructed with the stack ensembling method.The models classified five diseases: cataract, pathological myopia, glaucoma, diabetic retinopathy, and normal. The "faster ensembles" achieved 87% accuracy on the aggregated dataset of ocular illness images, but the "ensemble of ensemble" model attained an accuracy of 88%.

Sanghavi and Kurhekar (2024) did a literature survey, and their survey concentrated on eye disorders, associated symptoms, conventional diagnostic approaches, and AI-based systems, examining deep learning algorithms for automated screening and detection utilizing fundus images .A system utilizing three distinct CNNs achieved an accuracy of 97.08% in DR diagnosis. With the help of transfer learning, optimizing the hyper-

parameter, and the convolutional neural network, the system reached an impressive accuracy of 95.68%. in diabetic retinopathy categorization. Utilizing blinding cross-validation, a CNN with fourteen layers achieved an accuracy of 91.17% in AMD classification, whereas tenfold cross-validation yielded a higher accuracy of 95.45%.

Vyas et al. (2024) introduced an innovative “TBUT-based approach” for detecting the presence or absence of dry eye disease from video. On the basis of the TBUT, the suggested method accurately measures the condition of dry eyes and labels it as severe, normal, or moderate. The suggested method demonstrates outstanding efficacy of 83% in the classification of TBUT frames, the identification of dry eye disease, and the assessment of the severity of TBUT video. The proposed methodology's significant value is indicated by the 90% correlation between the ophthalmologist's assessment and the proposed method.

Tsiknakis et al. (2021) explored transfer learning and ensemble learning techniques and their efficacy and drawbacks in medical image analysis, particularly for diabetic retinopathy. They covered various aspects of the pipeline, including datasets, preprocessing techniques, and deep learning models such as ResNet, AlexNet, VGG16, GoogLeNet, InceptionV3, InceptionV4, Xception, Inception-ResNet, DenseNet, and SE-BN-Inception for disease diagnosis, grading, and lesion localization. Finally, they concluded that the VGGNet architecture reported the most accurate results with 95.68% accuracy for the classification of diabetic retinopathy.

Khan et al. (2022) presented a DL-based method for focused ocular detection. They utilized the VGG-19 image classification algorithm to categorize the ODIR dataset, which includes 5000 photos of eight fundus classes representing various ocular disorders. However, these classes have uneven datasets. To handle class imbalance, they converted the multiclass classification problem into a binary one. Their results showed that the VGG-19 model has achieved the highest accuracy of 98.13% for myopia.

The author of Sagvekar et al. (2024) proposed a “Hunter-Prey Ladybug Beetle Optimizer Deep Maxout Network (HPLBO_DMN)” model for “diabetic retinopathy” categorization. They started with image preprocessing. During preprocessing to diminish

noise, they used the “Kalman filter” and “Region of Interest (RoI)” extraction methods. Then preprocessed images were split into sub-bands using “Meyer wavelet” transformation. Lesion segmentation was done using ‘K-Net’. Concurrently, arteries and veins were classified using “Artery/Vein Classification Network (AVNet)”. Ultimately, DR classification process was done with the “Deep Maxout Network (DMN)” which was trained using proposed “HPLBO”. The proposed 'HPLBO_DMN' achieved 93.6% accuracy, 93.8% sensitivity, 92.9% specificity, and 92.9% segmentation accuracy.

Thanki (2023) examine color fundus images for diagnosing glaucoma. They proposed a “intelligent computer-aided triage system” using a “deep neural network (DNN)” and “machine learning”. Initially, DNN was used to extracts deep features from fundus pictures, then pictures were classified as glaucomatous image or not using several machine learning classifiers. Their result demonstrate that the combination of a DNN with logistic regression is best over all existing glaucoma classification techniques, achieving a classification performance characterized by an AUC of 100% and an accuracy of 99%.

Keenan et al. (2022) proposed a novel model “DeepLensNet” to automate the diagnosis and quantitative classification of three types of age-related cataracts: 'Nuclear sclerosis' using 45-degree slit-lamp images, cortical lens opacity, and Posterior subcapsular cataract using retroillumination photographs. The performance of DeepLensNet was subsequently compared to that of human evaluators, comprising 14 ophthalmologists and 24 medical students. “DeepLensNet" had a reduced MSE relative to both ophthalmologists and medical students, indicating superior accuracy in the quantitative assessment of cataract severity.

Peng et al. (2019) developed a deep learning model “DeepSeeNet”, to automatically classify patients by Simplified Severity Scale using bilateral color fundus images taken from “AREDS” dataset. The model attained an accuracy of 0.67 and a Cohen's kappa statistic of 0.56, which shows moderate agreement with the AMD severity grades assigned by retinal specialists.

Al-Fahdawi et al. (2024) developed “Fundus-DeepNet": Multi-label deep learning classification model for improved diagnosis of various eye illnesses by combining data of fundus pictures. Fundus-DeepNet system demonstrated AUC- 99.76 % in the off-site test set and 99.86 %, in the on-site test set.

Latif et al. (2022) developed a two-step model called “ODGNet” . The first step uses a “visual saliency map” with a shallow convolutional neural network to localize the optic disc from fundus pictures. The second step uses transfer learning-based approaches such as ResNet, AlexNet, and VGGNet to diagnose glaucoma. The authors then tested the nove model with five retinal datasets to classify normal and glaucomatous pictures. The results of experiment shows that for glaucoma detection, suggested “ODGNet” utilizing ORIGA dataset is the most accurate approach, exhibiting accuracy, specificity, sensitivity, and area under the curve of 95.75%, 94.90%, 94.75%, and 97.85%.

Ramanathan et al. (2021) developed a system to efficiently enable the identification of cataracts, glaucoma, and retinal disorders in patients. The techniques employed for detection include Logistic Regression, Random Forest, Gradient Boosting, and SVM. Gradient boosting demonstrates optimal efficacy for cataract-affected eyes, achieving 90% accuracy. Logistic regression attained 89% accuracy and random forest 86%.

Wahab Sait (2023) aims to construct an eye disease classification model utilizing deep learning (DL) techniques. Denoising autoencoders are employed for preprocessing of image to remove noise and artifacts. The essential features were extracted using single-shot detection (SSD) method. For feature selection “whale optimization algorithm” (WOA), incorporating “Levy Flight” and “Wavelet” search strategies were employed. The Adam optimizer is utilized for classifying fundus images. For model performance assessment, two datasets ODIR and EDC datasets, were employed. Accuracy and Kappa values for the suggested EDC model were 99.1 and 96.4 in the ODIR dataset and 99.4 and 96.5 in the EDC dataset.

Marouf et al. (2022) proposed a model that utilized machine learning (ML) and ranker-based feature selection approaches to efficiently detect ocular disorders. The model autonomously predicts one or more of five prevalent ocular diseases: “Acute Angle-

Closure Glaucoma (AACG)", "Cataracts" (CT), "Primary Congenital Glaucoma" (PCG), "Ocular Hypertension"(OH) , and "Exophthalmos"(BE). They used "train-test" and "stratified k-fold cross-validation" to split the data and employed nine machine learning methods. Ultimately, SVM surpassed other approaches, achieving the greatest accuracy of 99.11% after "10-fold cross-validation", whereas Logistic regression attained 98.58%.

Lee et al. (2020) proposed an image synthetic approach that transforms vessel pictures into vessel-centered pictures with enhanced clarity for identification, utilizing the multilayer perceptron framework of artificial neural networks. The researcher used high-resolution and low-resolution pictures of the same patient in a statistical analysis to see how well the proposed method worked at getting high-resolution vascular pictures from their low-resolution counterparts.

Winston and Hemanth (2021) proposed two modified "self-organizing" map networks for improving iris image categorization performance measures. The iris region was demarcated from the pupil and surrounding sclera using edge detection techniques and "Circular Hough Transform". The author mapped the annular iris from cartesian to polar coordinates using the "rubber sheet" model, giving it a rectangular shape. The classification process employed "self-organising" maps.

Prasad et al. (2019) suggested a "Deep Neural Network" model to identify the early stages of diabetic retinopathy and glaucoma. The proposed model was less complex and achieved an accuracy of 80%.

Zhu et al. (2024) conducted an analysis of several deep learning architectures, including CNN models, transfer learning strategies, and the application of datasets such as APTOS 2019 and EyePACS for the classification of diabetic retinopathy. Their research indicates that leveraging transfer learning has proven to be effective approach for overcoming the challenge of limited data availability often faced in context of "Diabetic Retinopathy" analysis. Convolutional Neural Network models like ResNet and VGGNet, with their deep and complex architectures, have emerged as the most widely utilized framework s for the task for the DR classification tasks. Notably, researchers have also explored the use of more computationally efficient deep learning model such as SqueezeNet and

MobileNet to classify diabetic retinopathy, particularly in the contexts with the restricted data availability and computational capabilities.

4. Description of Topic

In the field of healthcare, early diagnosis and classification of eye disorders are very essential for prevention of vision loss partially or completely. Vision loss can affect person's way of living by restricting him\her to do his\her daily activities which induce mental suffering. Early diagnosis of eye disease can prevent a person from blindness. The advancements in deep learning, a subset of artificial intelligence, have paved the way for remarkable breakthroughs in various fields, including the medical domain, where the accurate diagnosis and classification of eye diseases have become a crucial challenge.

With the advancement of digital eye scanning using fundus photography, "Optical Coherence Tomography (OCT)", "Optical Coherence Tomography Angiography (OCTA)" and "Deep Learning", it is now possible to identify retinal disease at early stage. Using automated computer systems eye specialists can examine fundus or OCT scans promptly with great accuracy. The incorporation of machine learning and deep learning methodologies has revolutionized the identification and monitoring of retinal disorders.

Deep learning has demonstrated a considerable promise in computer-assisted identification and localization of several eye disorders, including diabetic retinopathy, glaucoma, and cataracts etc. Convolutional neural networks (CNNs) have exhibited exceptional efficacy in categorizing retinal images into various illness classifications. The intricate characteristics of retinal diseases and the diversity of patient populations present obstacles in creating reliable and universally applicable models.

Challenges posed by Deep Learning Models in identifying retinal diseases:

- The variability in image quality resulting from diverse real-world imaging situations presents a problem in maintaining consistent model performance across photos of differing quality.
- The scarcity of publicly accessible data hinders the advancement and evaluation of robust models.
- Discrepancies in the recording and description of medical data might result in inconsistencies that question the efficacy of the applicability of the model and its

solution

- The majority of publicly available datasets pertain to diabetes, cataracts, and glaucoma; however, there is a paucity of data regarding conditions such as RVO, VID, ERM, and AMD

- The existence of severely imbalanced datasets presented considerable difficulties in the pre-processing of fundus/OCT pictures. There is a necessity for efficient image pre-processing methods to mitigate image noise and artifacts.

- Using single view of image as input to the model in retinal disease identification may constrain the model's efficacy. Multi-view approaches possess the capacity to markedly enhance performance of the model.

- The system's efficiency may be influenced by the uneven data distribution across various eye disease classifications. Inadequate data on particular illness may lead to skewed forecasts, as the system may struggle to integrate the traits of less common diseases.

- Challenges in discerning the impaired lesions from the images, which impacts the precision of the classification outcomes.

To address above challenges following research work will be carried out:

The main feature of the research is to apply transfer learning on the imaging data to enhance the classification of multiple retinal illnesses

The steps required for the research: -

1. Data Collection and integration of different dataset

2. Data Preprocessing: during this phase following stretegies can be carried out

    - Image enhancement
    - Image augmentation
    - Equal distribution of data in all the classes to reduce data imbalance

3 Build Models: Implementation would be followed in three steps

    I. Identify and apply Deep neural architectures for classification of retinal diseases from OCT/fundus images.

II. Extract features using CNN and apply Deep Learning Models for the classification of retinal diseases from OCT/Fundus images.

III. Creating a model by applying Transfer Learning for the classification of the Retinal Diseases

4. Train and validate the models: The proposed model is trained using transfer learning. Also, the model is trained with the pre-existing models.

5. Evaluate the model and Compare it with existing Models.

3. Problem Statement

To develop Deep Learning Models for Retinal Disease Diagnosis and Classification.

5. Research Objective

- To review the existing retinal disease detection and classification models.

- To develop a novel Deep Learning algorithm for retinal disease diagnosis at early stages.
- Develop an ensemble/hybrid approach to detect and classify the multiple retinal diseases.

6. Methodology

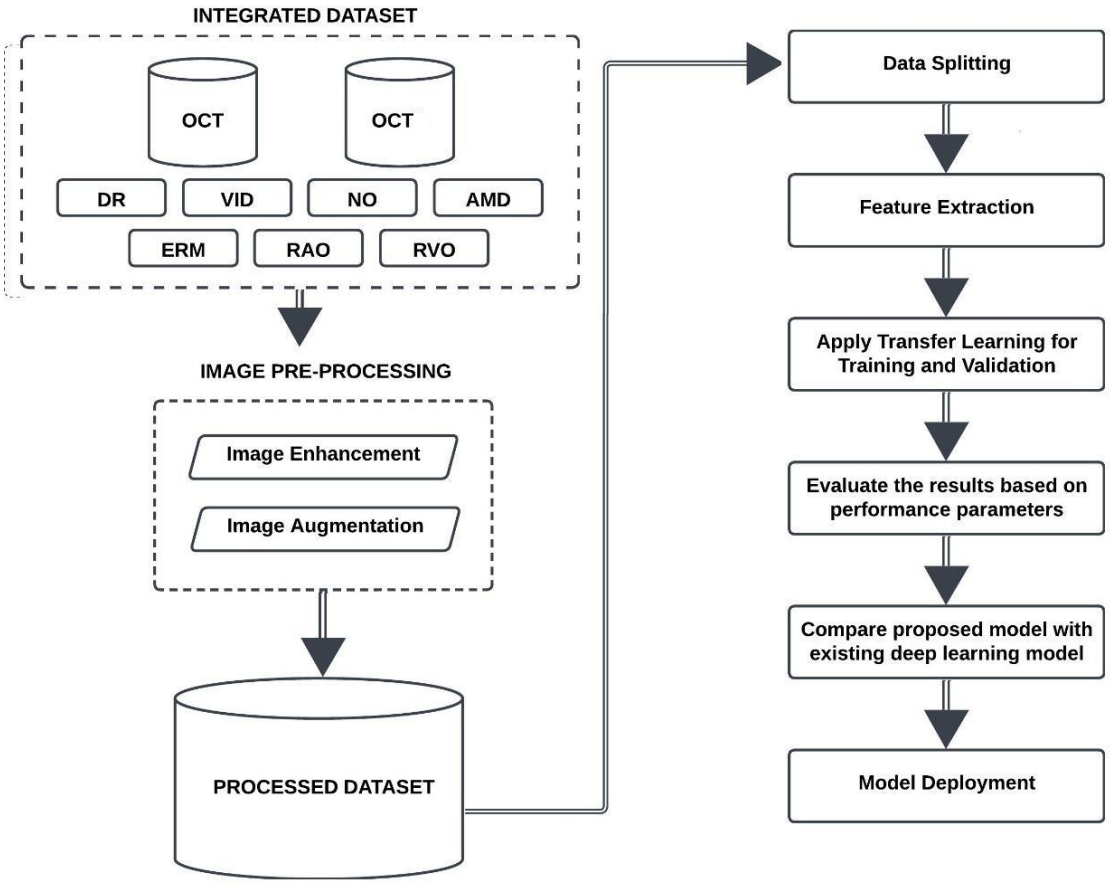

Figure 1: Workflow

Software to be used: Jupyter Notebook (Python3.x),

Development Tools: Jupiter Notebook, Google Colab: Free access to GPUs and

TPUs for Deep Learning.

Hardware to be used:

1. CPU: Intel Core i7/i9 or AMD Ryzen 7/9 (Intel Core i5 or Ryzen 5 for lighter tasks).

2. GPU: NVIDIA GTX 1650 (minimum) or NVIDIA RTX 3060/3070/3080/4090 for advanced tasks.

3. RAM: 16-32 GB

4. Storage: 256 GB SSD (minimum), 512 GB to 1 TB SSD (recommended for better performance

7. Expected Outcome of Research

Following will be the research outcomes:

- The proposed model aims to achieve classification of multiple retinal diseases with a level of accuracy surpassing that of current models.
- Additionally, the model will address diseases that have received limited research attention, such as retinal vein occlusion (RVO), AMD, ERM.
- The proposed model aims to assist ophthalmologists in detecting ocular diseases faster.

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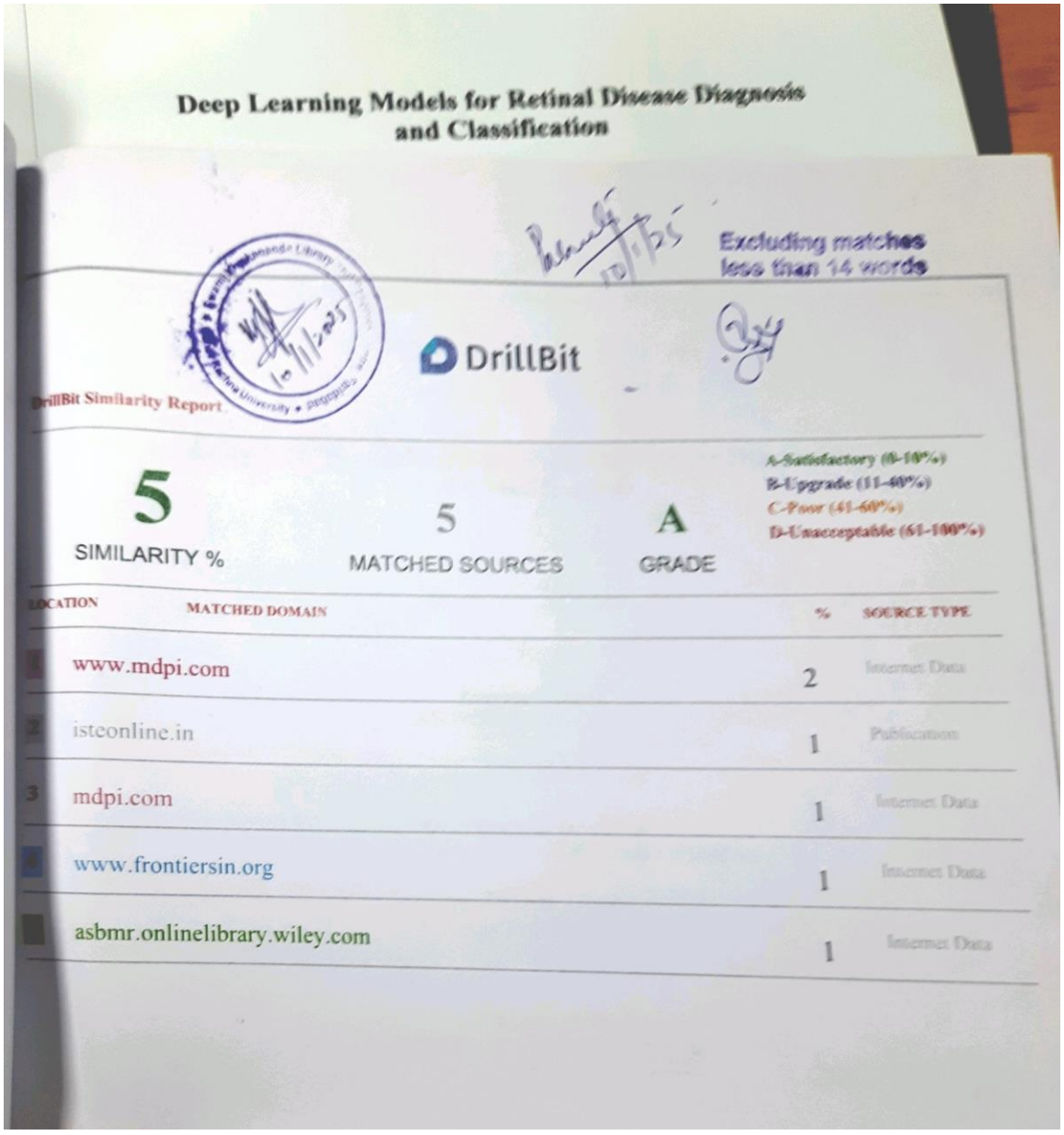

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SHORT SYNOPSIS

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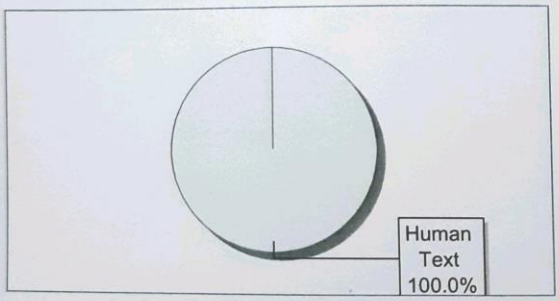

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